Free-Space Optical Communication for Spacecraft and Satellites including CubeSats in Low Earth Orbit (LEO)

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INTRODUCTION

- A new method for optical data transmissions from satellites using laser arrays for laser beam pointing
- Combines a lens system and a vertical cavity surface-emitting laser (VCSEL)/Photodetector Array, both mature technologies, in a novel way
- With further development, possible applications include communications from the Earth to spacecraft in Earth orbit and in deep space, such as at the moon and Mars
- A possible application is to the Artemis Program for CubeSats in low-Lunar Orbit (LLO), which use body pointing, by providing a fine pointing capability
- This system has been applied to satellites in low-Earth orbit, (LEO), in a study using computer simulations of the laser beam propagation

Comparison to Current Methods

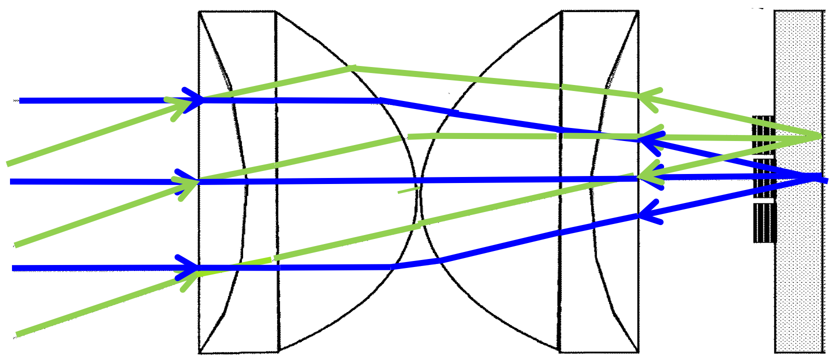
- Many current architectures use dynamical systems, (i.e., moving parts, e.g., fast-steering mirrors (FSM), and/or gimbals) to turn the laser to point to the ground terminal, and some use vibration isolation platforms as well
- The system is simple, static, compact, and provides accurate pointing, acquisition, and tracking (PAT)
- This static system has the potential to replace these current dynamic systems and vibration isolation platforms. The feasibility is dependent on studies for the particular application
- For these electro-optical systems, reaction times to pointing changes and vibrations are on the nanosecond time scale, much faster than those for mechanical systems
- For LEO terminals, slew rates are not a concern with this new system
- This system can improve the PAT system's size, weight, and power (SWaP) in comparison to current systems.

Optics Code

- Computer simulations used the optics code OpticStudio, from Zemax, LLC
- It has the capabilities to model the laser source and diffraction effects due to wave optics
- These capabilities make it possible to model laser beam propagation over space communication distances
- This code has been applied to satellites in LEO, using various lens systems
- In particular, an application has been made to NASA's Optical Communications and Sensors Demonstration (OCSD) program
- Fine pointing was provided by the new technology to augment body pointing used by OCSD
- The simulations for OCSD used a diffraction limited lens system and a VCSEL array.

NEW CONCEPT FOR LASER BEAM POINTING

Technical Approach



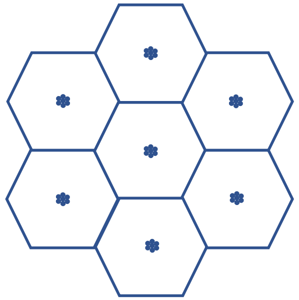
Lens System with (VCSEL)/ Photodetector Array

- An incoming laser beam (green or blue, with rightward arrows), transmitted from a ground terminal, enters the lens system, which directs it to an element of the pixel array (gray rectangle). Angle determines position
- Each element, or pixel, consists of a VCSEL component/Photodetector pair
- The photodetector detects the (possibly weak) signal beam, and the VCSEL component returns a strong modulated beam (green or blue, with leftward arrows) to the lens system, which sends it to the ground terminal
- As the incoming beam changes direction, e.g., from the blue to the green incoming direction, this change is detected by the photodetectors, and a laser adjacent to the detecting photodetector is turned on to keep the outgoing laser beam on target
- The laser beams overlap so that the combined returning beam continues to cover the ground terminal
- The VCSEL component may consist of a single VCSEL or a cluster of VCSELs.

NEW CONCEPT FOR LASER BEAM POINTING

VCSEL/ Photodetector Array

- Candidate VCSEL/ Photodetector Array



VCSEL Cluster

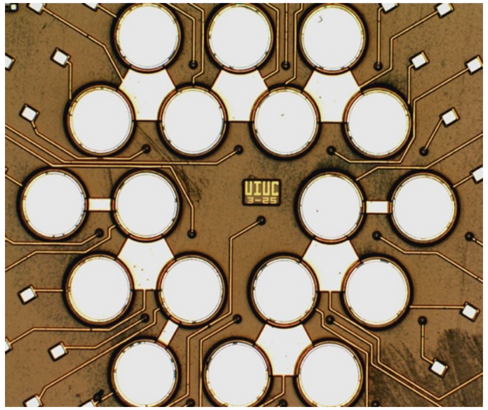
Photodetector

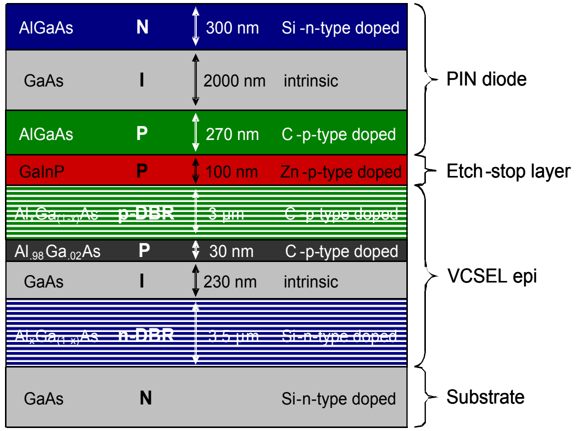
- Example of a fabricated VCSEL/Photodetector Array

  Photodetectors are p-type/intrinsic/n-type (PIN) detectors

Left: Top-view of a 37-element VCSEL / PIN detector array. VCSELs are small black dots and photodetectors are large white circles

Right: Side-view of the epi-structure used for the fabrication of integrated VCSEL / PIN detector arrays.





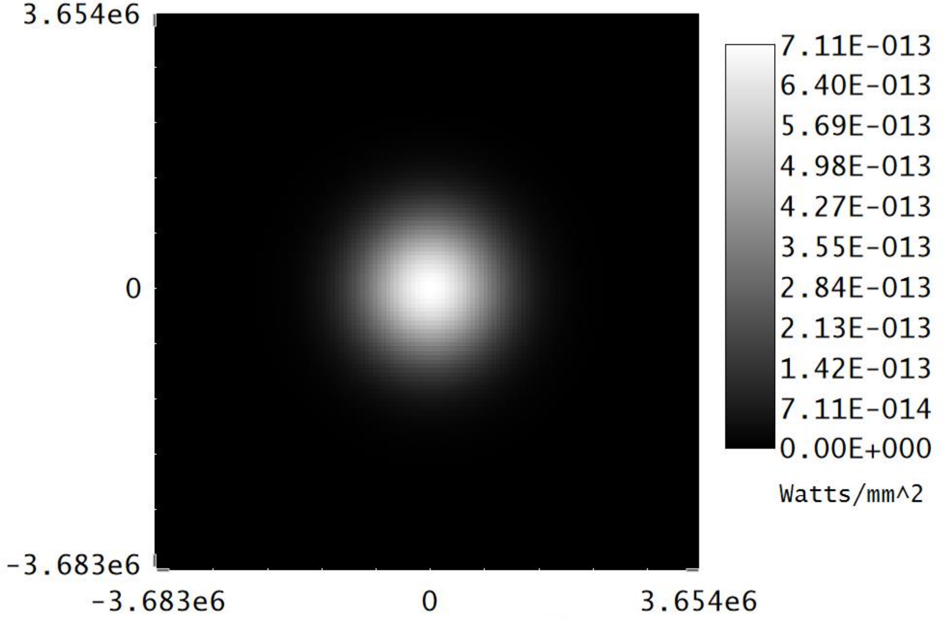
LEO Application

- NASA’s Optical Communications and Sensors Demonstration (OCSD) program
- New lens system will be used to augment a laser pointing system on a CubeSat that uses star trackers for body pointing
- New lens system provides a fine pointing capability to the OCSD lens system, which enables more accurate pointing
- Power requirement is substantially reduced and the resulting thermal load also reduced, thereby mitigating the current thermal load challenge

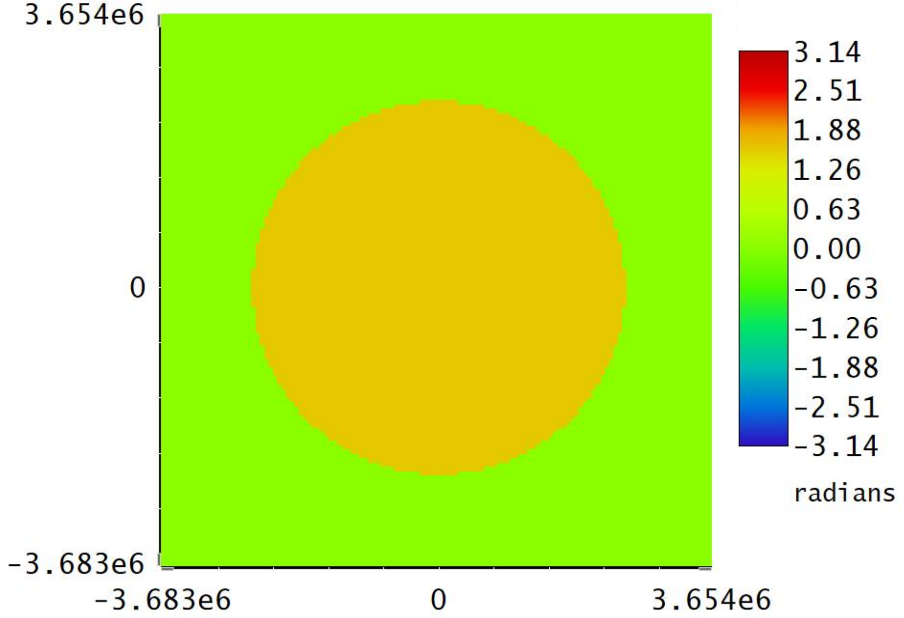
OCSD Bean Propagation

- Irradiance and phase of wave front at 611 km propagation, a LEO distance
- Laser beam divergence 0.14°, similar in divergence to beam propagated in OCSD
- Laser output power 2 W
- Irradiance Gaussian profile, phase is flat, so that beam is diffraction limited
- Distance units in mm and irradiance spot size diameter is about 1600 m

Irradiance



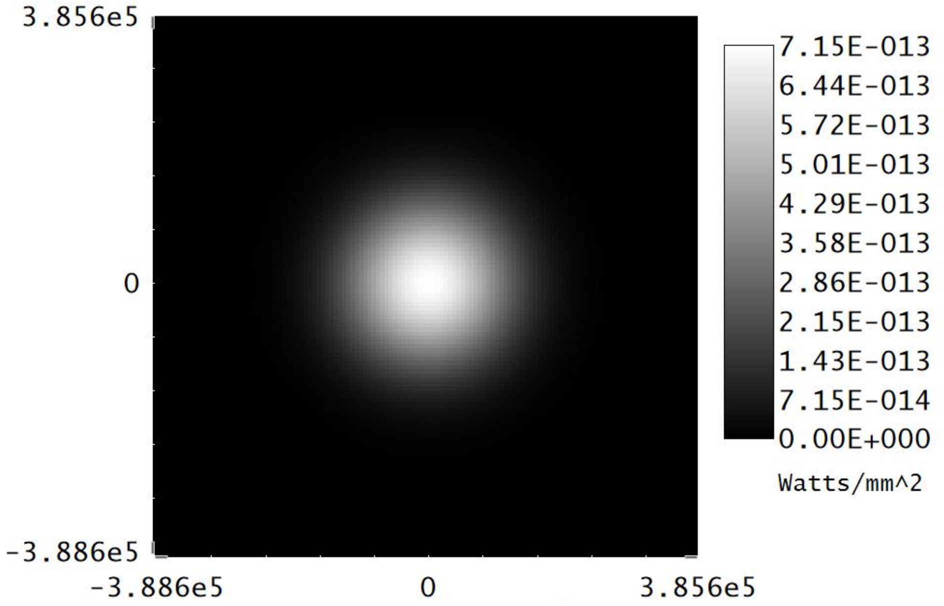
Phase



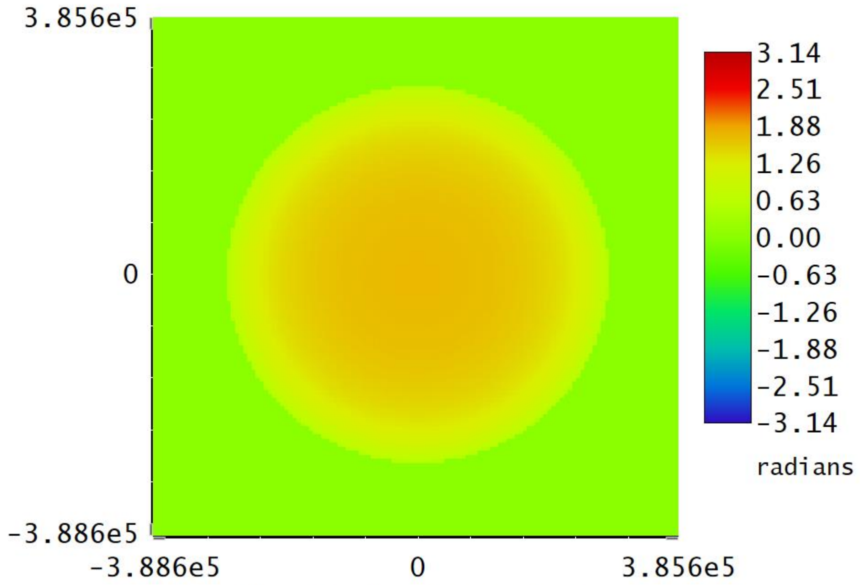
New Lens System Bean Propagation

- Irradiance and phase of wave front, 611 km propagation with new lens system
- Laser beam divergence 0.0.0174°, eight times smaller in comparison to OCSD
- Laser output power 3 mW, sixty six times smaller in comparison to 2 W of OCSD
- Peak irradiance is 7.15E-013 W/mm^2, in comparison to 7.13E-013 W/mm^2 of OCSD
- Irradiance Gaussian profile, phase is essentially flat, so beam is diffraction limited
- Irradiance spot size diameter is about 200 m, eight times smaller than for OCSD

Irradiance



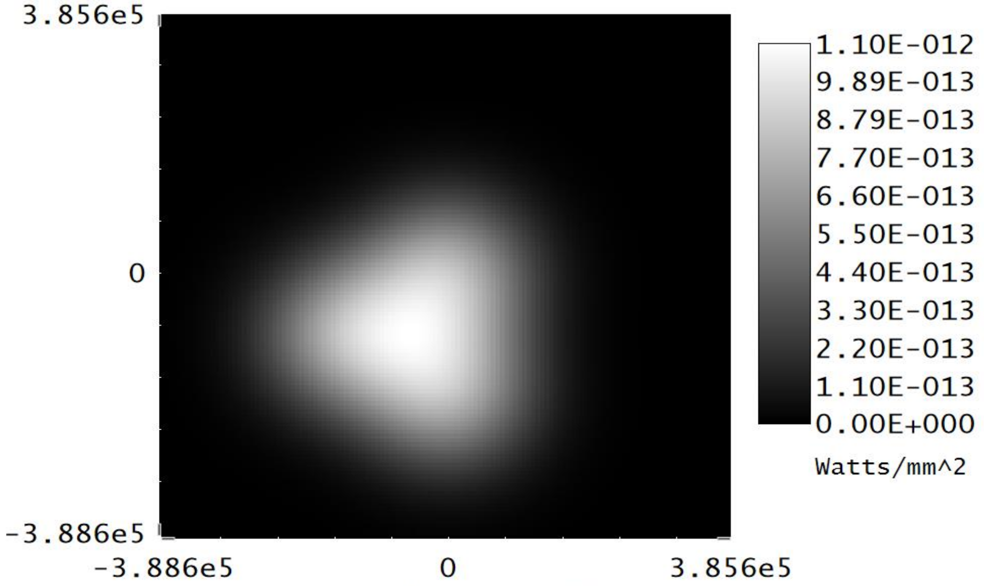
Phase



Overlapping Beams

- Irradiance from three incoherent overlapping beams
- Distance of 200 m between spot centers produces a plateau at the peak intensity.
- Using 42 VCSEL clusters, their beams would cover the area covered by the OSCD beam. (VCSEL arrays of thousands of VCSELs are routinely fabricated.)
- Now the new procedure for pointing could be applied. When a PIN detects an incoming signal beam, the VCSEL cluster at its center would be turned on
- As the incoming beam changes direction, this change is detected by an adjacent photodetector, and the laser cluster at its center is turned on to keep the outgoing laser beam on target, and the other laser cluster is turned off
- Two or three laser clusters could be kept on to insure that the target was within their combined coverage at the peak irradiance

Irradiance



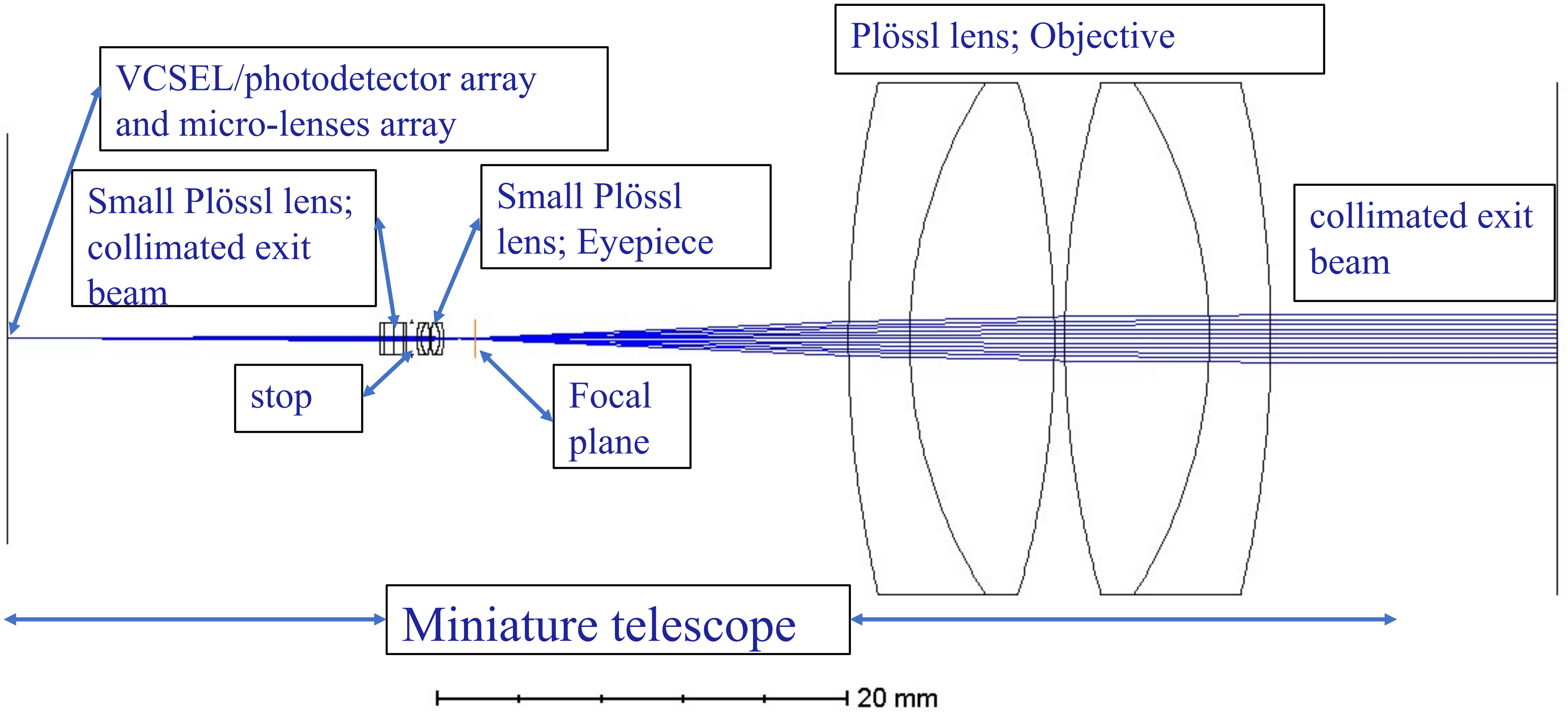
Concluding remarks

- A new method has been described for optical data transmissions from satellites using laser arrays for laser beam pointing.
- It combines a lens system and a VCSEL/Photodetector Array, both mature technologies, in a novel way.
- The system is simple, static, compact, and provides accurate pointing, acquisition, and tracking (PAT)
- This static system has the potential to replace current dynamic systems and vibration isolation platforms. The feasibility is dependent on studies for the particular application
- A possible application to the OCSD Program was described

Backup slides

New lens system using Plössl lenses

- Used in simulations



New lens system using Plössl lenses

- Being developed; smaller eyepiece Plössl lenses, micron size